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Steam Drum Level Measurement Compensation through the use of Constant Head Chamber with Dynamic Compensation

Lianwei Zhong, Cindy Wei, Henry Johnston
Chevron Phillips LLP
Emails: zhongl@cpchem.com, henryjesusjohnston@yahoo.com

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Abstract

The level measurement for high pressure steam drum, using differential pressure (D/P) transmitters, has been challenging and sometimes problematic because condensate/steam densities vary significantly with the pressure and the temperature. One additional source of measurement error is the difference in temperature between the differential pressure transmitter's reference legs. These factors could cause the level measurement to be off as much as 30% from the actual value for high pressure steam boilers, enough to exceed the tolerance established in the Safety Requirement Specification (SRS) for a Low-Low Steam Drum Level Safety Instrumented Function (SIF). The further the deviation from normal operating conditions, the greater the level measurement error. Because of this, the Low-Low Steam Drum Level SIF is not operative during the start-up, which is the riskiest operation mode.

This paper presents the use of temperature - equalizing columns (Constant Head Chambers) to minimize the temperature difference between the transmitter reference legs, and drum level compensated measurements through the use of dynamic selection of D/P range vs % Level depending on the steam drum operating pressure or dynamic calculation of saturated liquid/steam properties in SIS Logic Solver. This paper also addresses the challenges of implementing this method to meet measurement accuracy and safety integrity level requirements.

Introduction

Drum level measurement is one of the critical signals used in drum level control and drum level protection against hazardous scenarios. Typical DP based level measurement is shown in in Figure 1. Assuming the reference leg B is filled with water and its temperature is constant at the ambient conditions (68F or 100F etc.), the basic formulas are shown below:

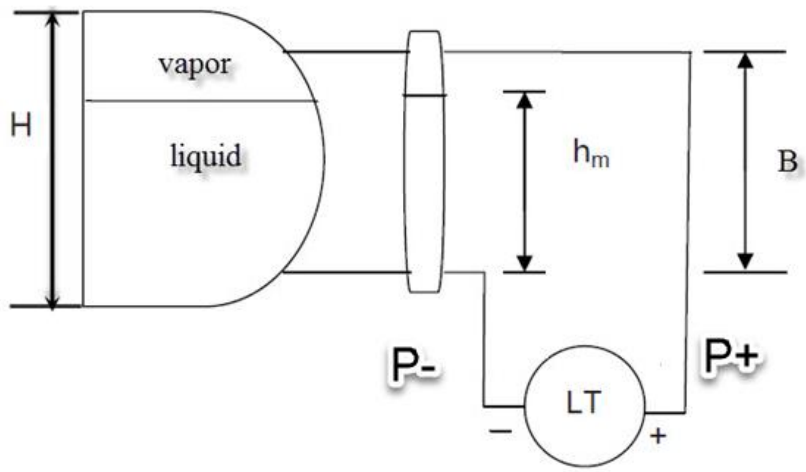

Figure 1: Schematic of Typical DP based Drum Level Measurement

$P_{upper\ leg} = P_+ = B * SG_B + (H - B) * SGv$ (Equation 1)

$P_{lower\ leg} = P_- = hm * SGw + (H - hm) * SGv$ (Equation 2)

$DP = (P_{upper\ leg}) - (P_{lower\ leg})$ (Equation 3)

$DP = [B * SG_B + (H - B) * SGv] - [hm * SGw + (H - hm) * SGv]$

$= [B * (SG_B - SGv) - hm * (SGw - SGv)]$ (Equation 4)

Where:

h_m: Actual steam drum level [inches]

h: Raw level measure by transmitter in SIS [inches]

H: The maximum steams drum height (inches)

B: The distance between upper tap and lower tap (inches)

SG_w: Specific gravity of saturated water inside the drum

SG_v: Specific gravity of saturated steam inside the drum

SG_B: Wet Leg water specific gravity at the ambient temperature

P: Hydrostatic pressure (inches W.C.)

The DP is measured and represented in DCS/SIS as raw drum level h typically; compensated level can be expressed as

$L=h_{m}/B=f\ (DP, SG_w, SG_v)= h_m=f\ (h, SG_w, SG_v)\ [\%]$ (Equation 5)

Constant Head Chamber Level Measurement Analysis

As indicated in the above definition, Specific Gravity SG_B is based on the assumption that the temperature in the upper leg is near ambient. Such assumption is not accurate in some cases. One way to reduce the uncertainty in the determination of the upper leg temperature is the use Constant Head Chamber/Reservoirs. It is intended to reduce the difference in temperature between the upper leg and the measurement (lower leg) section via “pipe inside pipe” method as shown in Figure-2. The lower half of chamber and section below that are insulated to make those sections adiabatic to the ambient, but the upper half of the chamber is exposed to air. It makes the vapor and liquid inside the chamber stay saturated at normal operation. The inner tube (wet leg) is quickly full of steam condensate, the potential over fill spills into the outer tub and connects back with the drum liquid. The inner wet leg (upper leg) is always full of the saturated water which has the same specific gravity of the liquid inside of the drum, so it maintains “constant head” pressure in the reference leg.

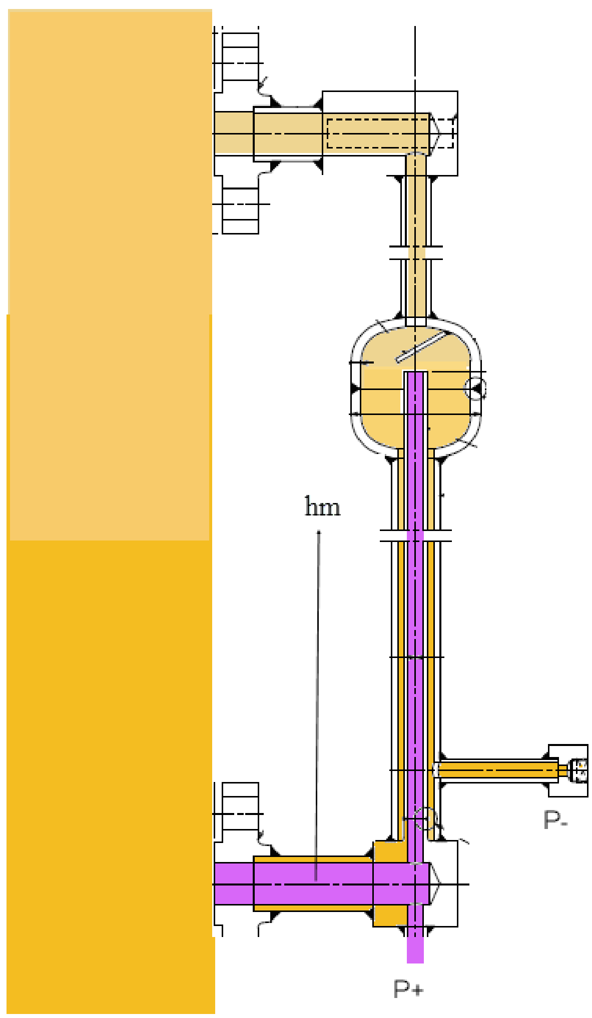

Figure 2: Schematic of Pipe in Pipe Constant Head Chamber (Permit from BBK Technologies)

Where:

Light yellow section: steam

Dark yellow section: liquid

Purple section: inner pipe filling of condensate, linked to transmitter lower pressure port

h_m: Actual steam drum level in the constant head chamber, linked to transmitter high port

Because of the use of Constant Head Chamber, we can now say:

$SG_B = SGw$ Equation (6)

Substituting Equation 5 in Equation 4

DP = $B * (SG_w - SGv) - \text{hm} * (SGw - SG\text{v})$ Equation (7)

Calling

ΔSG= $SG_w - SGv$ and substituting in Equation 6

DP= $B * \Delta\text{SG} - \text{hm} * \Delta\text{SG}$ Equation (8)

At 0% level hm=0, substituting in equation 7

$DP_{0\%} = B * \Delta SG$ Equation (9)

At 100%, hm=B, substituting in equation 7

$DP_{100\%} = 0$ Equation (10)

Pressure Compensation, Multiple Transmitter Ranges with dynamic switching

The linear relation between the differential pressure and the level is shown in Figure 3.

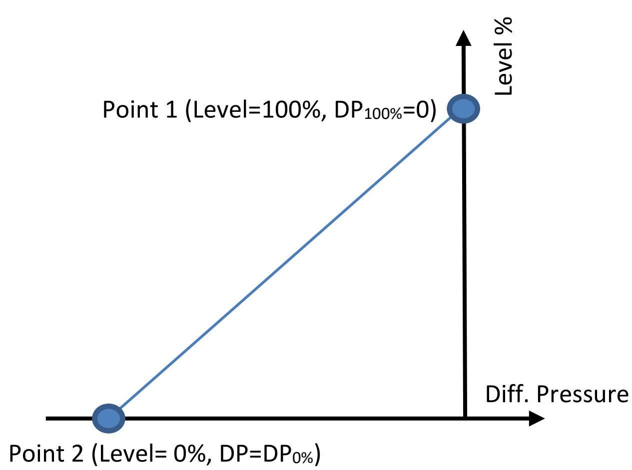

Figure 3. Linear Relationship of Differential Pressure vs Level

If two points of the straight line are known, the level at any point can be calculated as follows:

$L= L_2 + (L_2\text{-}L_1/\ DP_2\text{-}DP_1)*\ (DP\text{-}DP_2)$ Equation (10)

Using the data from Figure 3: L_1=100%, $DP_{100\%}$=0, L_2=0%, DP_2=$DP_{0\%}$

$L= -100\%/(\ DP_{0\%})*(DP\text{-}\ DP_{0\%})$ Equation (11)

Substituting Equation 9 in Equation 11

$L= -100\%/(\ B * \Delta SG)*(DP\text{-}\ B * \Delta SG)$ Equation (11)

Where:

L: Actual compensated steam drum level [%] =hm/B

For a boiler with an operating range from start-up equal to atmospheric pressure to a design pressure of 2085 psig, 18 pressure segments were selected. For each one of those pressure segments a Level equation was calculated using Equation 12 and data from ASME Steam Tables. Within those segments the inaccuracy is limited within 2%.

Function Block

Inputs: P (Drum pressure); DP (LT Dif. Pressure) (Median value for LTX,Y,Z)

If P ≤ 20 psig	then	L=1.4708*(DP+68.991)
If 20 psig < P ≤ 135 psig	then	L=1.5701*(DP+64.625)
If 135 psig < P ≤ 525 psig	then	L=1.6707*(DP+60.735)
If 525 psig < P ≤ 745 psig	then	L=1.8712*(DP+54.225)
If 745 psig < P ≤ 1135 psig	then	L=1.9709*(DP+51.484)
If 1135 psig < P ≤ 1335 psig	then	L=2.1581*(DP+47.018)
If 1335 psig < P ≤ 1485 psig	then	L=2.2645*(DP+44.808)
If 1485 psig < P ≤ 1635 psig	then	L=2.3527*(DP+43.128)
If 1635 psig < P ≤ 1685 psig	then	L=2.4501*(DP+41.415)
If 1685 psig < P ≤ 1735 psig	then	L=2.4845*(DP+40.840)
If 1735 psig < P ≤ 1785 psig	then	L=2.5207*(DP+40.254)
If 1785 psig < P ≤ 1835 psig	then	L=2.5579*(DP+39.668)
If 1835 psig < P ≤ 1885 psig	then	L=2.5970*(DP+39.071)
If 1885 psig < P ≤ 1935 psig	then	L=2.6373*(DP+38.475)
If 1935 psig < P ≤ 1985 psig	then	L=2.6788*(DP+37.878)
If 1985 psig < P ≤ 2035 psig	then	L=2.7234*(DP+37.259)
If 2035 psig < P ≤ 2085 psig	then	L=2.7710*(DP+36.618)
If 2085 psig < P	then	L=2.8204*(DP+35.977)

Output: Compensated LT(%)

This calculation bases on the traditional method using transmitter measured raw drum level h then compensated with saturation pressure, but it breaks the traditional link between uncompensated drum levels with transmitter settings. It measures D/P directly and uses dynamic value of $DP_{0\%}$ and $DP_{10\%}$ calculated from drum dynamic pressure.

Pressure Compensation using Function Block in SIS Logic Solver

Based on the similar idea of above, Equation 8 can be re-arranged to express hm as unknown

As now, $DP= B * \Delta SG - hm * \Delta SG$ Equation (8)

Moving hm *ΔSG to the left side of equation

$$\mathrm{hm} \ast \Delta\mathrm{SG} = B \ast \Delta\mathrm{SG} - \mathrm{DP} \qquad \text{Equation (8)}$$

$$\mathrm{hm} = \frac{B \ast \Delta\mathrm{SG} - \mathrm{DP}}{\Delta\mathrm{SG}}$$

$$\mathrm{L} = \frac{hm}{B} = 1 - \frac{DP}{\Delta\mathrm{SG} \ast \mathrm{B}} \qquad \text{Equation (8')}$$

In this method, as long as DP can be measured accurately from field transmitter, then by means of calculation capability of current SIS logic solver, the custom function blocks can be built to calculate differential specific gravity based on saturated pressure, then the drum level can be calculated and compensated correctly as well.

During the implementation, ASME Steam Table Compact Edition Table-2 is broken into 22 pressure segments. The algorithm determines which segment of the steam tables will be used based on the steam pressure from zero psig to 2085 psig. Another function blocks is built to calculate the drum level L based on Equation 8.

Building the function block of specific gravity differential curve with drum pressure utilizes the advance of computation capability in current DCS/SIS; it makes the relationship between drum level with DP and drum pressure simple and easy to understand. Furthermore, the measurement accuracy is improved with the full pressure range; the difference between the compensated readings and independent magnet level measurement is within 1%.

SIL Verification due to adding steam pressure compensation

The Steam drum pressure transmitter is a key element in the level compensated measurement. The switching between transmitter ranges depends on its indication. A false signal could cause a selection of an inappropriate range, which may not be able to meet the tolerance specified in the SRS, and probably defeating the protection. It is recommended to include such transmitter in the SIL verification. The input group voting should be 2oo2 of the pressure and level transmitters.

Conclusions

1. Constant header chamber's compensation reduces the temperature uncertainty of the differential pressure transmitter upper leg. Its main function is to equalize the condensate in upper leg and the steam drum water temperature. This equalization helps to simplify the equations used for pressure compensation.
2. This paper introduces a practical and convenient way of steam drum level measurement compensated by pressure, using multiple level equations with automatic switching depending on the pressure measurement.
3. This pressure compensation approach allows low-low steam drum level SIF functional during the start-up, design operation, off-design etc. operating modes.
4. modularity of functionality makes complex measurement/calculation easy to implement
5. The hardware used for pressure compensation (pressure transmitter) shall be included as part of the SIF and validated through the SIL verification.

References:

1. ASME Steam Tables Compact Edition
2. Power Industry Division Newsletter Spring 2012-- Steam Drum Level Measurement Temperature Equalizing Column Concerns, Dale P. Evelyn, P.E.
3. Instrument Engineer’s Handbook--Process Measurement and Analysis, 4th Edition, Bela G. Liptak
4. ANSI/ISA-84.00.01-2004 Part 1(IEC 61511-1 Mod)